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Screening attenuation as the measure of electromagnetic properties of converter cables

Abstract

Screening attenuation as the measure of electromagnetic properties of converter cables is one of screen effectiveness determinants. Catalogue data rarely includes this cable parameter, especially with division into frequency ranges. The paper presents results of investigations of screening attenuation in a wide frequency range for chosen types of screened cables. The triaxial method was used for testing cable parameters according to the standard PN-EN 50289-1-6 [1]. The rightness of using double screened cables in converter systems was confirmed. It will facilitate to provide electromagnetic compatibility of the system.

Keywords: electromagnetic compatibility, screening attenuation, converter cables.

1. Introduction

Ensuring the electromagnetic compatibility of converter drives often requires to use additional means of electromagnetic disturbance reduction in the form of interference filters [2], [3]. It poses a big problem in case of very complex systems equipped with converter drives, like in different types of traction vehicles. It is very time-consuming and expansive, at the completed vehicle stage, to reduce the emission of electromagnetic conducted and radiated disturbances to permissible levels according to standards. At the design and construction stage, there is a possibility for proper selection of converter cables with respect to their attenuation parameters. The screening attenuation parameter is usually provided by manufacturers of telecommunication cables. In the case of cables used in converter drive systems, catalogue data rarely provides that parameter. The only reference to screen effectiveness evaluation is a type of the screen and description of its performance. By taking into consideration the way of screen production, its effectiveness may be only roughly determined.

The effectiveness of cable screen can be determined by making suitable measurements. Numerous publications present mainly results of transfer impedance measurements of screened cables [4], [5]. The standard PN-EN 50289-1-6: Communication cables – Specifications for test methods. Part 1-6: Electrical test methods – Electromagnetic performance [1] is the basic document, which describes the methods of cable testing. The paper presents the test results of the converter cable screening attenuation in a wide frequency range from 1 MHz to 1 GHz with the use of the triaxial method. The comparison of the obtained results was performed for chosen screened cable types with division into frequency subranges.

2. Parameters determining the quality of a screened cable screen

The electromagnetic properties of non-symmetric cables depend only on the screen quality. In the case of symmetric screened cables, their electromagnetic properties depend on non-symmetry attenuation as well as on screen effectiveness. The screen effectiveness can be determined by measurements of a transfer impedance or screening attenuation [4], [5]. The combined effect of non-symmetry attenuation and screening attenuation can be determined by measurement of coupling attenuation [1].

Transfer impedance Z_T of a homogenous cable with small electrical length is defined as the ratio of a longitudinal voltage induced in the outer circuit (environment) and a current in the inner circuit (cable), referred to the unit length.

Screening attenuation is a proper criterion for description of the screening effectiveness of cables with a high electrical length. The screening attenuation is defined as the ratio in logarithmic scale of the power inserted into a cable and the maximal peak radiated power.

By introducing a signal with P_{feed} power to a cable, due to electromagnetic coupling between the cable and the environment, surface waves radiating in both directions on the screen surface are induced. On the basis of the measured peak values of the surface current we can calculate the maximal peak power $P_{rad,max}$ in the outer circuit composed of the cable screen and environment. P_{feed} and $P_{rad,max}$ power ratio, expressed in logarithmic scale in dB is defined as the coupling attenuation [1].

According to the standard PN-EN 50289-1-6, a few different measurement methods may be used for telecommunication cables to determine parameters defining their electromagnetic properties. The transfer impedance of a cable is determined by the triaxial method or the line injection method. The screening attenuation is determined by the triaxial method or the absorbing clip method, while coupling attenuation only by absorbing clip method. Publications, e.g. [4], present calculation and simulation methods for determining discussed parameters of telecommunication cables.

3. Screening attenuation of screened cables

Screening attenuation is a ratio of the power inserted into a cable (P_{feed}) and the maximal peak radiated power ($P_{rad,max}$) [1]:

$$a_s = 10 \cdot \log_{10} \left| \frac{P_{feed}}{P_{rad,max}} \right| \tag{1}$$

Due to maladjustment of the outer circuit, the voltage variation appears at the far end. It results from electromagnetic coupling through the screen and overlapping partial waves spreading towards the inner and outer end. Full reflection resulting from the short circuit at the near end of the outer circuit affects the total voltage of partial waves spreading towards the inner and outer end, appearing at the receiver input connected to the far end of the outer circuit. This voltage is measured as a voltage varying with overlapped periods in the frequency range. The characteristic impedance of the outer circuit is independent of the maximum value of the total overlapping voltages. The diagram and variation of the screening attenuation characteristic depend on the relations between the coupling length of the tested cable and the electrical length of the wave.

The coupling length is electrically short for:

$$\lambda_0/L_c \geq 10 \cdot \sqrt{\varepsilon_{r1}} \;\; or \;\; f \cdot L_c \leq \frac{c}{10 \cdot \sqrt{\varepsilon_{r1}}} \tag{2}$$

or electrically long if:

$$\lambda_0/L_c \leq 2 \cdot |\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}| \;\; or \;\; f \cdot L_c \geq \frac{c}{2 \cdot |\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}|} \tag{3}$$

where:
L_c – coupling length in [m],
λ_0 – wave length in open space in [m],
c – light velocity in vacuum $3*10^8$ [m/s],
ε_{r1} – relative permeability of dielectric in the cable,
ε_{r2} – relative dielectric permeability of the outer circuit, ε_{r2}≈1.1.

Besides of the cable coat, the relative dielectric permeability of the outer circuit is close to 1.

4. The method and test stand for testing the screening attenuation of screened cables destined for a converter

In the triaxial method, a measuring set for screening attenuation consists of three coaxial elements [1]. The tested circuit consists of an outer and inner circuit, where the inner circuit is the tested cable, while the outer one consists of a screen and coaxial pipe (Fig. 1). An aluminum pipe with the inner diameter of 50 mm and length of 2.2 m acts as the outer conductor of the outer circuit and it is connected to the screen at the side of the signal input. The inner diameter of the pipe in relation to the cable screen diameter is to ensure the characteristic impedance of the outer circuit equal or higher than a receiver input resistance. The pipe must be long enough to wave overlapping in narrow frequency ranges. One end of the cable is loaded with well screened resistor R_1, whose value equals the characteristic impedance of the coaxial system Z_1. The method of determining the unknown characteristic impedance Z_1 is precisely described in the standard PN-EN 50289-1-6. There is a joint on the other end of the circuit, which enables connection with a generator. Properly made connections ensure that the contact resistance in the range of high frequencies does not influence the obtained measurement results. A coaxial arrangement of the tested cable ensures that there are not introduced any additional reflections which distort the measurement results.

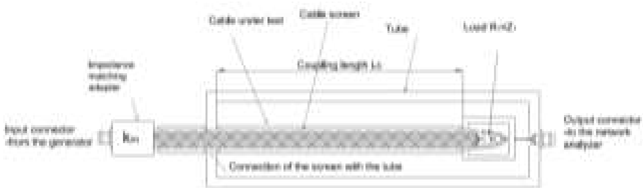

Fig. 1. The arrangement for determining the screening attenuation of screened cables

There were chosen two types of screened cables for testing: LiYCY 4x2.5 mm^2 (single screen) and 2YSLCY 4x2.5 mm^2 (double screen) destined for converter systems. The first one contains the screen made of tinned copper strings with coverage density of 80%, while the second one contains the screen made of aluminum foil and screen made of tinned copper wire braiding with coverage density of 80%. The screened cables tested are considered as a quasi-coaxial circuit and all conductors were connected together at both ends. Double screens also are connected together on both ends along the whole circumference. The tested cable sample was connected to a generator, the outer circuit (pipe) and a spectrum analyzer. The measurement of the voltage ratio at the output of the outer circuit and at the input of the tested cable was made with automatic frequency tuning in the whole measure range. The spectrum analyzer Rohde&Schwarz type FSL3 with the operating frequency range from 9 kHz to 3 GHz equipped with a generator with bandwidth 1 MHz – 1 GHz was used for measurements.

The determined impedance of the inner circuit Z_1 (characteristic impedance of the tested cables), and through it load resistance R_1 is less than 50 Ω (receiver input impedance). That is why the impedance conforming system from Fig. 2 was used. The resistance values were calculated according to (4):

$$R_s = 50 \cdot \sqrt{1 - \frac{R_1}{50}}, \qquad R_p = \frac{R_1}{\sqrt{1 - \frac{R_1}{50}}}. \tag{4}$$

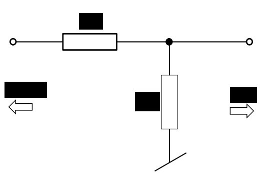

Fig. 2. The arrangement of the conforming system

The system amplification k_m according to (5) amounts 0.181.

$$k_m = \frac{R_1 \cdot R_p}{R_1 \cdot R_p + R_p \cdot R_s + R_1 \cdot R_s} \tag{5}$$

We get the value of the conforming system attenuation after substituting the calculated value k_m into the formula:

$$a_z = 20 \cdot \log_{10}\left(\frac{1}{k_m}\right) = 14.8\ [dB]. \tag{6}$$

To determine the real value of the screening attenuation, the losses introduced by the conforming system and connection cords must be taken into account. The attenuation of the connection cords was included in the calibration process.

The screening attenuation of the cable a_S in [dB] at the standardized environment impedance was calculated from formula (7):

$$a_s = 20 \cdot \log_{10}\left|\frac{U_1}{U_2}\right|_{min} + 10 \cdot \log_{10}\left(\frac{2 \cdot Z_s}{Z_1}\right) - a_Z, \tag{7}$$

where:
a_Z– conforming system attenuation in [dB],
Z_1– characteristic impedance of the tested cable in [Ω],
Z_S– standardized environment impedance in [Ω] (equals 150 Ω),
U_1– voltage at the generator output in [V],
U_2– voltage at the receiver input in [V].

The view of the measuring stand equipped with the system used for testing the screening attenuation of converter cables is shown in Fig. 3. The measuring stand was verified by measurements of a coaxial cable of type RG58CU with the known value of screening attenuation >50 dB.

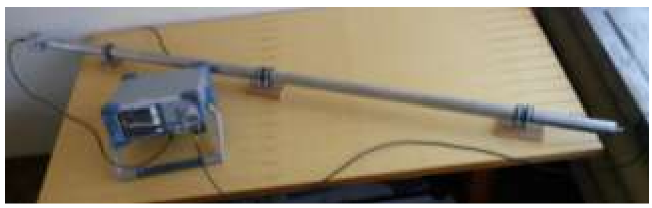

Fig. 3. View of the measuring stand

5. Measurement results

The measurement of screening attenuation for two types of cable was made in the frequency range from 1 MHz to 1 GHz with division of the given range into the subranges: 1 MHz-100 MHz, 100 MHz-500 MHz, 500 MHz-1 GHz. Due to this, we can get more precise information about the screening attenuation in a particular frequency bandwidth and similarity of the tested parameter than that obtained from the measurement in the whole range.

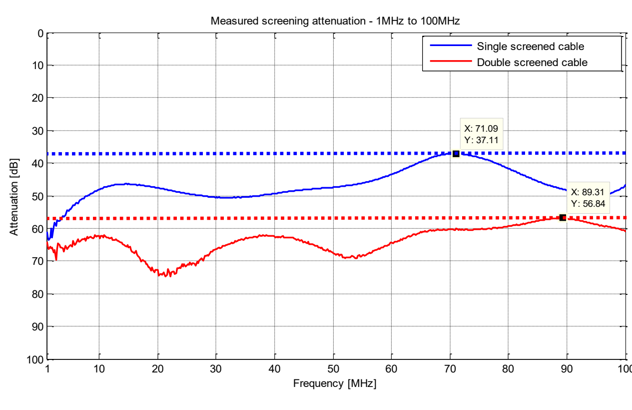

Fig. 4. Screening attenuation in frequency range 1 MHz – 100 MHz

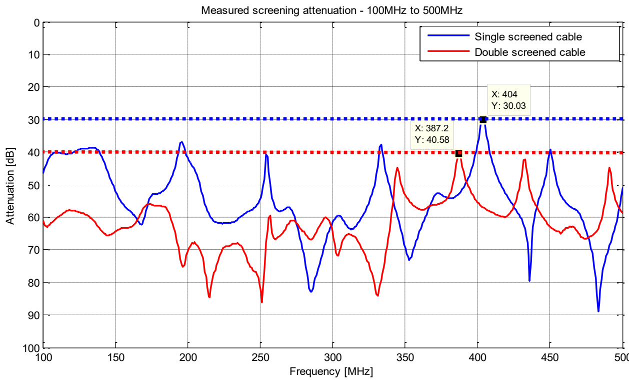

Fig. 5. Screening attenuation in frequency range 100 MHz – 500 MHz

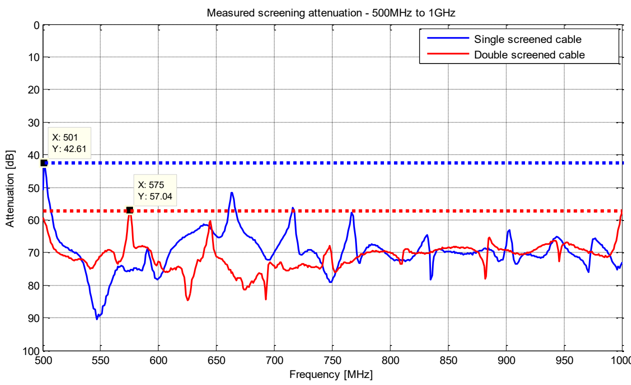

Fig. 6. Screening attenuation in frequency range 500 MHz – 1000 MHz

The plots shown above present a comparison of the screening attenuation measurement results for a single and double screened cable. The obtained results show that in all the frequency bandwidths the double screened cable has a higher level of screening attenuation. An evident difference in the tested parameter can be noticed for compared cables. Both cables reach the maximum attenuation value in the frequency range from 500 MHz to 1 GHz (Fig. 6). The minimum attenuation value for both tested cables occurs in the frequency range from 100 MHz to 500 MHz (Fig. 5).

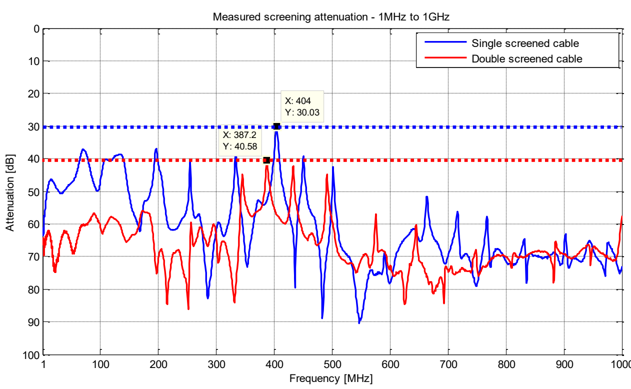

Fig. 7. Screening attenuation in frequency range 1 MHz – 1 GHz

Taking into consideration the whole frequency range from 1 MHz to 1 GHz (Fig. 7) the minimum value from all the subranges (obtained for the bandwidth 100 MHz to 500 MHz) was assumed as the resultant screening attenuation for both cables.

Table 1 contains the minimum values of the screening attenuation of both tested cables for particular frequency subranges and the resultant value of the screening attenuation for the full measurement range from 1 MHz to 1 GHz.

Tab. 1. Screening attenuation

	1 MHz-100 MHz	100 MHz-500 MHz	500 MHz-1000 MHz	1 MHz-1000 MHz
Single screened cable	37.1 dB	30.0 dB	42.6 dB	30.0 dB
Double screened cable	56.8 dB	40.5 dB	57.0 dB	40.5 dB

The screening attenuation for the single screened cable amounts to 30 dB and 40.5 dB for the double screened one (Table 1).

6. Summary

The paper presents the methodology and exemplary results for determining one of the parameters defining electromagnetic properties of cables applied in converter drive systems. The screening attenuation of cables was the determined and analyzed parameter. The measuring stand was made according to the measuring method description and advices included in the standard. The stand was also verified through measurements.

The obtained screening attenuation results for two cable types with different screen construction let us determine the level of this parameter for converter cables. The division of the conducted tests into subranges allows us to indicate the frequency bandwidths where the screening effectiveness is the highest and where it is the lowest.

When comparing the obtained results, we can notice a significant advantage of the screening attenuation for the cable with double screen in all frequency bandwidths. On the basis of the made measurements and analysis, we can confirm the correctness of applying double screened cables in converter systems. It will result in limiting emitted electromagnetic disturbances and providing electromagnetic compatibility of a system.

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7. References

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